Stock Assessment and Restoration of the Afognak Lake Sockeye Salmon Run

Annual Report for Study 04-412

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Abstract

Afognak Lake sockeye salmon *Oncorhynchus nerka* runs declined substantially in 2001 and subsequent escapements from 2002-2004 have been well below the escapement goal. Responding to concerns from local subsistence users, the Alaska Department of Fish and Game began investigations of the lake's rearing environment. With successful completion of a one-year mark-recapture feasibility study to estimate smolt abundance in 2003, a three-year study (2004-2006) to continue the smolt abundance estimates and assess rearing and spawning habitats was funded.

During 2005, the third year of operation, 73,697 sockeye salmon smolt were captured using a Canadian fan trap operated from 10 May to 27 June. Using mark-recapture techniques, we estimated that 560,230 sockeye salmon smolt (95% C.I. 486,554 – 633,906) emigrated from Afognak Lake. The population was composed of 521,025 age-1. and 39,205 age-2. smolt. Age-1. smolt had a mean weight of 3.9 g, a mean length of 76.8 mm, and a mean condition factor of 0.84. Age-2. smolt had a mean weight of 4.2 g, a mean length of 81.3 mm, and a mean condition factor of 0.77.

Five limnology surveys were conducted in Afognak Lake from May to September, 2005. Seasonal water chemistry and nutrients concentrations were consistent with historical data collected from Afognak Lake. Afognak Lake is considered phosphorus limited. Seasonal zooplankton density averaged 116,764 animals per m^{-2}, and cladocerans comprised 61.2% of the zooplankton sampled. The cladoceran *Bosmina* was the most abundant zooplankter, while *Epischura* was the most abundant copepod.

The spawning habitat in major and minor tributaries surrounding Afognak Lake was evaluated in the fall of 2005. Based on the total tributary survey there is enough available spawning habitat to support an estimated 15,297 sockeye salmon. Aerial surveys of lake shoal spawners of Afognak Lake were conducted on three occasions in August and September of 2005. The peak survey revealed a total of 770 spawning sockeye salmon spawning along the lake shoals.

Rearing conditions within Afognak Lake appear to be stable or improving since lake water chemistry and nutrients were similar to historic levels, and zooplankton abundance did not suggest overgrazing. Favorable rearing conditions were also reflected in the relatively high condition factor of the smolt (>0.70) that enabled most of them to emigrate at age-1.

Key words: Afognak Lake, Afognak Island, age, emigration, escapement, Kodiak Island, *Oncorhynchus nerka*, smolt, sockeye salmon, subsistence harvest, trap, zooplankton.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

Appendix | Page

INTRODUCTION

Afognak Lake sockeye salmon *Oncorhynchus nerka* runs declined substantially in 2001, and subsequent escapements during 2002-2004 were well below the established sustainable escapement goal (SEG) range of 40,000 to 60,000 fish (Wadle 2001; Schrof and Honnold 2005). In 2005 a new escapement goal of 20,000 to 50,000 sockeye salmon was adopted by the Alaska Board of Fish (Nelson et al. 2005). The 2005 escapement (21,577) was also below the previously established escapement goal but was within the newly established biological escapement goal (BEG) range. As a result of these low returns, the commercial sockeye salmon fishery in Afognak Bay was closed for the three year period during 2002-2004 (Table 1). Sport fishing restrictions were also implemented through in-season closures and reduced bag limits from 2001 to 2004. In conjunction with commercial and sport fishing closures, State and Federal managers closed subsistence fishing in early June during the 2002 season, and in-season closures occurred in 2003 and 2004. The 2002 subsistence fishing closure was unprecedented in the Kodiak Management Area (KMA) and caused subsistence fishing effort to shift to other systems. Subsistence salmon fishing has been allowed in Afognak Bay for pink *O. gorbuscha* and coho *O. kisutch* salmon starting 1 August each year.

The Afognak Lake sockeye salmon run has historically provided for the largest subsistence salmon fishery on Afognak Island and the second largest in the Kodiak Archipelago (Schrof and Honnold 2005). Local villagers from Port Lions and Ouzinkie as well as Kodiak area residents have been the traditional users harvesting Afognak Lake bound sockeye salmon. The subsistence fishery is prosecuted within the Alaska Maritime National Wildlife Refuge. Subsistence harvests in Afognak Bay from 1990 to 2005 have ranged from 567 (2004) to 12,412 (1997) sockeye salmon (Table 1). The smallest documented subsistence harvests have occurred during the past four years (2002-2005); subsistence fishery closures occurred in three (2002-2004) of the past four years.

After Afognak Lake experienced poor returns and fisheries closures in 2002, local subsistence users, represented by the Kodiak-Aleutian Islands Regional Advisory Council, Kodiak Fish and Game Advisory Committee, and Kodiak Tribal Council, contended that a continued closure of the Afognak system would make it more difficult for local residents to harvest sockeye salmon and would shift fishing effort to the Buskin River and small sockeye salmon runs in the area. The Regional Advisory Council, Kodiak Advisory Committee, and Kodiak Tribal Council informed the Alaska Department of Fish and Game (ADF&G) and U.S. Fish and Wildlife Service (FWS) that the Afognak Lake sockeye salmon run failure constituted an emergency situation for their constituents. In response to this problem, the ADF&G received funding through the Office of Subsistence Management (OSM), Fisheries Resource Monitoring Program to determine the feasibility of estimating sockeye salmon smolt production from Afognak Lake. This study showed that sockeye salmon smolt could be effectively trapped in Afognak River and their abundance reliably estimated using mark-recapture techniques (Schrof and Honnold 2005). Sockeye salmon mortality rates are usually greatest during the freshwater life history stage (Burgner 1991); thus, smolt abundance studies are important in that they assess the relative success of the entire freshwater rearing stage ranging from egg deposition to subsequent smolt emigration.

In addition to smolt production estimates, ADF&G felt it was important to collect limnology data to determine the smolt production capacity of Afognak Lake. The ADF&G and Kodiak Regional Aquaculture Association had fertilized (1990-2000) and stocked juveniles into (1992, 1994, 1996-1998) Afognak Lake to restore the sockeye salmon run. As part of the evaluation process, limnological data (phosphorus-nitrogen, chlorophyll *a*, and zooplankton) were collected three years prior to, during, and three years after rehabilitation activities. However, limnology data collection was scheduled to end after 2003, unless the ADF&G obtained additional funding for the continued collection of limnological data to determine the factors that would limit sockeye salmon production during freshwater rearing. Based on the findings from the 2003 feasibility study, OSM provided funding for a three-year study (2004-2006) that would continue smolt assessment work and examine rearing and spawning potential of Afognak Lake. This report provides results from the second year (2005) of this study.

Objectives of the Project in 2005

The project objectives were to:

1) estimate the number of sockeye salmon smolt by age emigrating from Afognak Lake,
2) determine the average weight, length, and condition factor of the smolt,
3) estimate the timing by age class of the sockeye salmon smolt emigration from Afognak Lake,
4) evaluate the water chemistry, nutrient status, and plankton production of Afognak Lake and,
5) measure the useable spawning habitat available for sockeye salmon in the Afognak Lake drainage.

Background

Federal and State agencies have operated weirs to count salmon on various systems within the KMA since the early 1920s (Spalinger 2006). A weir has been operated on the Afognak River annually since 1978. Weir counts along with catch data (commercial, subsistence, and sport) have provided managers with an estimate of adult sockeye salmon production, but little information on juvenile production has been collected.

Juvenile production studies have been conducted in conjunction with limnological investigations at a number of sockeye salmon systems in the Kodiak archipelago, although only limited information on juvenile production has been collected for Afognak Lake (White et al. 1990; Schrof et al. 2000). Most projects on juvenile sockeye salmon production in Kodiak area systems have provided data for evaluating possible effects of over-escapement (Akalura, Frazer and Red Lakes; Kyle et al. 1988; Barrett et al. 1993a,b; Coggins 1997; Coggins and Sagalkin 1999; Sagalkin 1999), or were part of lake rehabilitation projects (Malina and Karluk Lakes; Kyle and Honnold 1991; Schrof and Honnold 2003). These studies estimated smolt abundance and size by age using trapping and mark-recapture techniques. Currently, juvenile production data are being collected from six sockeye salmon systems in the Kodiak archipelago and on the Alaska Peninsula (Schrof and Honnold 2003; ADF&G 2005). Sagalkin and Honnold (2003) assessed potential sources of error in mark-recapture estimates from smolt enumeration projects, including mortality caused by marking, handling, and trapping, and bias associated with smolt size and behavior. Effects of these sources of error were judged to be negligible.

Freshwater production of sockeye salmon has been examined within a variety of systems within Alaska by enumerating sockeye salmon smolt emigrating from lakes and measuring primary and secondary production in these lakes (Koenings et al. 1987). Primary production within lakes is driven by both physical conditions, such as temperature and dissolved oxygen, which affect nutrient cycling (Schlesinger 1991), and nutrient concentrations, especially phosphorous and nitrogen, which are required for photosynthesis (Spalinger and Bouwens 2003). Chlorophyll *a* levels are used as indicators of phytoplankton standing crop, which provide food for zooplankton that in turn are eaten by juvenile sockeye salmon. Zooplankton abundance, individual size, and species composition can be regulated from the bottom-up by phytoplankton availability (Stockner and MacIsaac 1996), or by top-down pressures such as grazing by juvenile sockeye salmon (Kyle 1992). Zooplankton population attributes are sometimes used by the ADF&G to determine juvenile stocking rates and juvenile salmon rearing capacity (Kyle et al. 1990; Honnold 1997; Honnold and Schrof 2001).

Finally, the amount and quality of available spawning habitat also determines sockeye salmon freshwater production. Little information is available on spawning habitat within the Afognak Lake system. White et al. (1990) reported unpublished results of a spawning habitat survey conducted sometime during the 1970s at Afognak Lake, but the methods used were not recorded. Current information on spawning habitat area and quality is needed to fully understand the productivity potential of the Afognak Lake system (Honnold and Edmundson 1993; Willette et al. 1995).

Description of Study Area

The Afognak Lake system is located on the southeast side of Afognak Island approximately 50 km northwest of the city of Kodiak (Figure 1). Afognak Native Corporation owns the land surrounding the system, but most subsistence fishing occurs in Afognak Bay, which is part of the Alaska Maritime National Wildlife Refuge. Afognak Lake (58^{o} 07' N, 152^{o} 55' W) lies about 21.0 m above sea level, is 8.8 km long, 0.8 km wide at its widest point, and has a surface area of 5.3 km^2 (White et al. 1990; Schrof et al. 2000). The lake has a mean depth of 8.6 m, a maximum depth of 23.0 m, and a lake-water residence time of 0.4 years (Figure 2). Runoff from Afognak Lake flows in an easterly direction via the 3.2 km Afognak River, which flows into Afognak Bay.

In addition to sockeye salmon, resident fish in the Afognak Lake drainage include pink salmon, coho salmon, rainbow trout (anadromous and non-anadromous) *O. mykiss*, Dolly Varden *Salvelinus malma*, three spine stickleback *Gasterosteus aculeatus*, and coastrange sculpin *Cottus aleuticus* (White et al. 1990). Chinook *O. tshawytscha* and chum *O. keta* salmon have also been observed in the Afognak River on occasion, but have not established viable spawning populations (White et. al 1990).

METHODS

Smolt Assessment

Trap Deployment and Assembly

A Canadian fan trap (Ginetz 1977) was installed on 10 May, approximately 32 m upstream from the confluence of the Afognak River in Afognak Bay. The fan trap was positioned towards the middle of the river, where water velocity was sufficient to minimize smolt avoidance (Figure 3). A live box (1.2 m x 1.2 m x 0.5 m) was attached to the cod end of the trap, and the entire trapping device was suspended by cable attached to a come-along and secured to an aluminum pipe frame, which allowed trap position to be adjusted in response to water level fluctuations. Perforated (3.2 mm) aluminum sheeting (1.2 m x 2.4 m) supported by a Rackmaster®[1] pipe frame was placed at the entrance of the trap in a "V" configuration to divert smolt into the live box. Trapping ceased, and the trap was removed from the river on 28 June, when smolt abundance declined and the number captured was less than 100 per day for three consecutive days. Detailed methods for trap installation, operation, and maintenance are described by the ADF&G (2005).

Smolt Enumeration

Smolt were captured in the trapping system and held in the attached live box until they were counted. During the evening (2200 to 0800 hours), the live box was checked every one to two hours, depending on smolt abundance. During the day (0801 to 2159 hours), the live box was checked every three to four hours. Smolt were removed from the live box with a dip net, counted, and either released downstream of the trap or transferred to an in-stream holding box for sampling and marking. Species identification was made by visual examination of external characteristics (Pollard et al. 1997). All data, including mortalities, were entered on a reporting form each time the trap was checked.

Age, Weight, and Length Sampling

A total of 200 sockeye salmon smolt were sampled each statistical week to obtain age, weight, and length (AWL) data. To reach the weekly total, daily samples of 40 sockeye salmon smolt were collected for five days within each statistical week. Smolt were collected throughout the night and held in the in-stream live box. The number of smolt collected each hour was proportional to emigration abundance. Forty smolt were randomly collected from those retained in the live box and

[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

sampled to obtain daily AWL data. After sampling, all smolt were released downstream from the trap.

Tricaine methanesulfonate (MS-222) was used to anesthetize smolt prior to sampling. Fork lengths (FL) were measured to the nearest 1 mm, and weights were recorded to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. After sampling, smolt were held in aerated buckets of water until they recovered from the anesthetic, and subsequently released downstream from the trap. Age was estimated from scales observed with a microfiche reader (EYECOM 3000) at 60X magnification, and recorded in European notation (Koo 1962).

Condition factor (Bagenal and Tesch 1978), a quantitative measure of "fatness," was determined for each smolt as:

$$K = \frac{W}{L^3} 10^5 \tag{1}$$

where,

K	=	smolt condition factor;
W	=	weight in g;
L	=	FL in mm.

Trap Efficiency and Population Estimates

Mark-recapture experiments were performed to measure smolt trap efficiency. Sockeye salmon smolt were marked (dyed) and released once per week and also when changes were made to the trapping system. Based on smolt studies at Akalura Lake (Coggins and Sagalkin 1999; Sagalkin and Honnold 2003), we attempted to achieve trap efficiencies between 15 to 20%. To achieve the desired trap efficiency and be within the relative abundance error (r) of 25% in estimating the total emigration, we needed to mark and release 300-500 smolt (Robson and Regier 1964; Carlson et al. 1998). To obtain the needed number of smolt to mark, we sometimes had to capture and hold smolt over a two-night period. When the desired number of smolt was collected, they were placed in an aerated 33-gallon trashcan filled with water and transported in a trailer pulled by an all terrain vehicle, to the release site approximately 1,240 m upstream. At this site, smolt were dyed with Bismark Brown Y dye at a ratio of 1.9 g to 15 gallons of continuously oxygenated water. The smolt were held in the dye solution for 30 minutes before being transferred to a holding box at the release site. Between 2100-2300 hours, the majority of the dyed smolt (~400) were randomly selected from the holding box, counted, and released across the width of the stream while the remaining dyed smolt (~100) were counted and left in the holding box. Dyed smolt from both groups that displayed unusual behavior (labored breathing, flared gills, side swimming, etc.) were removed from the experiment and released downstream of the trap. The remaining smolt left in the holding box (~100) were evaluated over the course of the following five days to determine the composition of delayed mortality. The proportion of fish that suffered mortally was applied to the released smolt (M_h). All dyed smolt recaptured at the trap site were counted and assigned to a dye test period (hereafter referred to as a stratum).

Trap efficiency for each stratum (*h*) was calculated by dividing the total number of dyed smolt recaptured by the number of dyed smolt released within the stratum:

$$u = \frac{m_h}{M_h} \tag{2}$$

where,

u = exploitation rate of the smolt population;

M_h = number of marked smolt released minus the estimated mortalities in stratum h;

m_h = number of marked smolt recaptured in stratum h.

A modification of the stratified Peterson estimator (Carlson et al. 1998) was used to estimate the number of smolt emigrating within each stratum:

$$\hat{U}_h = \frac{u_h(M_h + 1)}{m_h + 1} \tag{3}$$

where,

U_h = total number of smolt in stratum h;

u_h = number of unmarked smolt recaptured in stratum h;

Variance of the exploitation rate estimate was calculated as:

$$v\left(\hat{U}_h\right) = \frac{(M_h + 1)(u_h + m_h + 1)(M_h - m_h)u_h}{(m_h + 1)^2(m_h + 2)} \tag{4}$$

Smolt AWL samples for each stratum were used to estimate the number and size of smolt within each age class. The percentage for each age class was multiplied by the smolt estimate in each stratum to determine the emigration by age by stratum. Each age class of smolt in each stratum was summed to provide a total estimate by age, and total estimates by age were summed to provide an estimate of the total smolt emigration.

Limnological Assessment

Sampling and laboratory analysis methods were adopted from Schrof et al. (2000).

Lake Sampling Protocol

Five limnological surveys of Afognak Lake were conducted at approximately 4-5 week intervals from May to September, 2005. Two stations, marked with anchored mooring buoys and confirmed with Global Positioning System (GPS) equipment, were sampled from a float-equipped aircraft during each survey (Figure 2). Zooplankton samples were collected at both stations, but water samples were only collected at Station 1. Water samples for general chemistry and nutrient analysis were collected during each survey at a sample depth of 1 m below the water surface. Water samples were collected using a 6-L opaque Van Dorn sampler, and each sample was emptied into a pre-cleaned polyethylene carboy which was kept cool and dark in the float of the plane until processed at the laboratory in Kodiak. Vertical zooplankton hauls were made at each station using a 0.2 m diameter conical net with 153 μm mesh. The net was pulled manually at a constant speed (~0.5 m sec^{-1}) from approximately 2 m off the lake bottom to the surface. The contents from each tow were emptied into a 125-ml poly-bottle and preserved in 10% neutralized formalin.

General Water Chemistry and Nutrients

For analysis of color and dissolved inorganic nutrients, a portion of each sample was filtered through a rinsed 47 mm-diameter Whatman GF/F cellulose fiber filter and stored frozen in phosphate free soap-washed poly bottles. Frozen filtered water was also used for analysis of total phosphorus (TP), total Kjeldahl nitrogen (TKN), and general water chemistry, and these measurements were also made for frozen unfiltered and refrigerated (4^{o} C) water stored in clean poly bottles (Koenings et al. 1987). The pH of water samples was measured with an Orion 499A meter, while alkalinity (mg L^{-1} as $CaCO_3$) was determined from 100-ml of water titrated with 0.02 N H_2SO_4 to a pH of 4.5 and measured with a pH meter (AHPA 1985).

Reactive silicon was determined using the method of ascorbic acid reduction to molybdenum-blue after Stainton et al. (1977). Total filterable phosphorus (TFP) and filterable reactive phosphorus (FRP) were determined by the molybdate blue-ascorbic acid method (Murphy and Riley 1962) modified by Eisenreich et al. (1975). TP was analyzed after potassium persulfate-sulfuric acid digestion using the FRP procedure (Eisenreich et al. 1975). Samples for nitrate + nitrite (NO_3^- + NO_2^-) and ammonia (NH_4^+) were analyzed on a Spectronic Genesys 5 Spectrophotometer using the cadmium reduction and phenylhypochlorite methods outlined in Stainton et al. (1977). Analysis of TKN was completed using the Macro-Kjeldahl/Phenate methods described in Clesceri et al. (1998) in converting nitrogen to ammonia. This determines the concentrations of organic nitrogen and total ammonia. Total nitrogen (TN), the sum of TKN and nitrate + nitrite, was calculated for each sample in addition to the ratio of TN to TP (TN:TP).

Chlorophyll *a*

For chlorophyll *a* (chl *a*) analysis, 1.0 L of water from each sample was filtered through a Whatman GF/F filter under 15 psi vacuum pressure. Approximately 2 ml of magnesium chloride ($MgCO_3$) were added to the final 50 ml of water near the end of the filtration process. Filters were stored frozen and in individual plexiglass slides until analyzed. Filters were then ground in 90% buffered acetone using a mechanical tissue grinder, and the resulting slurry was refrigerated in separate 15-ml glass centrifuge tubes for 4 hours to ensure maximum pigment extraction. Pigment extracts were centrifuged, decanted, and diluted to 15 ml with 90% acetone (Koenings et al. 1987). The extracts were analyzed fluorometrically with a Turner 112 fluorometer equipped with a F4T5B lamp and calibrated with purified chl *a* (Sigma Chemical).

Zooplankton

For zooplankton analysis, cladocerans and copepods were identified according to taxonomic keys in Pennak (1989) and Thorp and Covich (1991). Zooplankton were measured in triplicate 1 ml subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Lengths from a minimum of 15 animals of each species or group (typically animals are grouped at the genus level) were measured to the nearest 0.01 mm, and the mean was calculated. Biomass was estimated from species-specific linear regression equations between length and dry weight derived by Koenings et al. (1987). Zooplankton data from the two stations were averaged for each survey.

Spawning Habitat Assessment

The available spawning habitat for sockeye salmon in the Afognak Lake drainage was evaluated in 2005. All tributaries that emptied into Afognak Lake were surveyed on foot in August. Each tributary was evaluated for potential spawning habitat. If the tributary was accessible to salmon it was measured from the stream terminus at the lake shore to a physical impediment blocking salmon migrating upstream. Sections of the tributary with similar physical characteristics (i.e., stream bank topography, water velocity, substrate, and canopy) were separated into sections (rectangular area) for evaluation. In addition, useable spawning habitat was defined as areas having water flow of approximately 0.5 m sec^{-1}, water depths of 0.3-0.5 m, gravel sizes of 6-150 mm with <25% by volume of gravel ≤6 mm, and minimal substrate compaction (Chambers et al. 1955; Honnold and Edmundson 1993). The total useable tributary spawning habitat was determined by estimating the percentage of useable habitat in each surveyed section and multiplying the useable percentage by the estimated total area for that section and then summing all sections for a total available area (Honnold and Edmundson 1993). The tributary habitat carrying capacity for sockeye salmon was obtained by:

$$OCT_i = UHT_i F \tag{5}$$

where OCT_i is the optimum sockeye salmon spawning capacity per block of tributary habitat, UHT_i is the usable habitat measured in each block, and F is the optimal sockeye salmon spawning density of one female per 2.0 m^2 (Burgner et al. 1969). The overall spawner capacity of tributary habitat was obtained by:

$$\sum OCT_i \tag{6}$$

The lakeshore habitat was evaluated by aerial survey of the lakeshore on three separate occasions in August and September, 2005. The observer looked for active spawning, salmon build up along the lake shore, and post spawning indicators (redds).

RESULTS

Smolt Assessment

Enumeration and Sampling

Smolt trapping was conducted a total of 49 days from 10 May to 27 June 2005. During this period, 73,697 sockeye salmon smolt were captured (Table 2). The greatest daily sockeye salmon smolt catch was obtained on 24 May when 5,365 smolt were captured (Table 2; Figure 4). Large daily smolt catches were also obtained on 21 May when 5,081 fish were captured.

Age, Weight, and Length Sampling

All of the 1,313 sockeye salmon smolt sampled for AWL data were assigned ages (Table 3). Samples collected from the first stratum of the emigration (10-21 May), were composed of 81.8% age-1. and 18.2% age-2. smolt. Samples collected in the second stratum (22-26 May), consisted of 96.5% age-1. smolt. The contribution of age-1. smolt throughout the remainder of the 2005 emigration (27 May – 27 June) never fell below 99.8% (Figure 5).

Age-1. smolt had a mean weight of 3.9 g (range – 2.8 g to 5.6 g), a mean length of 76.8 mm (range – 71.7 mm to 84.8 mm), and a mean condition factor of 0.84 (range - 0.75 to 0.92; Table 4). Age-2. smolt had a mean weight of 4.2 g (range – 4.0 g to 6.4 g), a mean length of 81.3 mm (range – 78.0 mm to 97.0 mm), and a mean condition factor of 0.77 (range - 0.75 to 0.82).

Trap Efficiency and Population Estimates

Four mark-recapture experiments were conducted during the sockeye salmon smolt emigration period (Table 2). Trap efficiencies ranged from 8.3% in the second experiment (22 to 26 May) to 28.0% in the fourth experiment (8 to 27 June). Mean trap efficiency for all experiments was 14.9%.

The total number of sockeye salmon smolt emigrating from the Afognak Lake system in 2005 was estimated to be 560,230 (95% C.I. 486,554 – 633,906; Table 5). The emigration was composed of 521,025 age-1. (93.0%) and 39,205 age-2. (7.0%) smolt (Table 6).

Limnological Assessment

General Water Chemistry and Nutrients

Hydrogen ion concentrations (pH) averaged 6.8 units with little seasonal variation (Table 7). Alkalinity levels (measured as $CaCO_3$) ranged from 9.8 mg L^{-1} to 12.5 mg L^{-1} and averaged 11.0

mg L^{-1} for the five samples collected. Results from the pH and alkalinity tests were similar to historical data collected from Afognak Lake and from other Kodiak archipelago lakes (Schrof and Honnold 2003).

Seasonal silica concentrations ranged from 2,465.1 to 3,271.8 µg L^{-1} and averaged 2,764.1 µg L^{-1} (Table 7). Concentrations were highest in May and progressively decreased through June, July and August and increased slightly in September.

Seasonal mean TP concentrations were variable, ranging from 5.3 to 16.3 µg L^{-1} and averaged 11.4 µg L^{-1} (Table 8). Seasonal inorganic phosphorous concentrations of TFP ranged from 4.6 µg L^{-1} to 13.6 µg L^{-1} and averaged 7.6 µg L^{-1}(Table 8). FRP concentrations ranged from 1.1 to 9.0 µg L^{-1} and averaged 3.6 µg L^{-1}.

Nitrogen levels were measured in three forms: TKN, NO_3^- + NO_2^-, and NH_{4+}. The seasonal mean TKN was 161.0 µg L^{-1}, and the greatest seasonal variation was between the May (238.0 µg L^{-1}) and July (127.0 µg L^{-1}) samples (Table 8). Seasonal NH_{4+} levels averaged 4.4 µg L^{-1} and ranged from 3.1 to 7.9 µg L^{-1}. Seasonal NO_2 + NO_3 levels averaged 40.5 µg L^{-1} and had a wide range of variability throughout the season, ranging from 7.4 to 90.9 µg L^{-1} (Table 8). TN concentrations ranged from 148.0to 328.9 µg L^{-1} and averaged 201.5 µg L^{-1}. The seasonal TN:TP ratio, by weight, averaged 20.5:1 (Table 8).

Chlorophyll *a*

Seasonal chl *a* concentrations ranged from 0.96 µg L^{-1} to 1.28 µg L^{-1} and averaged 1.15 µg L^{-1} (Table 7).

Zooplankton

Zooplankton weighted mean density was 116,764 animals per m^{-2} (Table 9). All zooplankton identified were crustaceans commonly referred to as either cladocerans (*Order* Anomopoda and Ctenopoda) or copepods (*Order* Calanoida, Cyclopoida, and Harpacticoida). Cladocerans were the predominate zooplankter (61.2% of mean) in the samples, with the genus *Bosmina* being most abundant (56.7% of mean). The other cladoceran genera included, *Daphnia* (2.5% of mean), *Holopedium* (1.3% of mean), and a group we called “Other Cladocerans,” which consisted of *Polyphemus* and various unidentified immature cladocera which were much less abundant (0.8% of mean). Of the copepods (38.8% of mean), the genus *Epischura* was most abundant (18.7% of the mean) followed in abundance by a group we called “Other copepods” (14.6% of the mean), which consisted mostly of the genus *Harpaticus* and various unidentified, nauplii (larvae). The copepod genus *Cyclops*, considered an important member of the zooplankton community in sockeye salmon lakes, were not very abundant (4.7% of mean). The genus *Diaptomus* made up the smallest portion of the copepods at 0.7% of the mean. There were many more cladocerans and copepods found in samples collected at station 1 than in samples from station 2.

Zooplankton mean biomass was 128.3 mg per m^{-2} (Table 9). Despite greater numbers of cladocerans, copepods comprised 54.7% of the zooplankton mean biomass due to their larger size (Table 9). The copepod genus *Epischura* represented the greatest percentage of biomass (46.1%), followed by the cladoceran genus *Bosmina* (40.0%). The remaining biomass was mostly comprised of *Cyclops* (5.4%) and *Daphnia* (3.4%).

The copepod *Epischura* was the largest zooplankter, having a mean length of 0.79 mm (Table 9). Of the remaining copepods, *Diaptomus* had a mean length of 0.73 mm, and *Cyclops* had a mean length of 0.63 mm. *Daphnia*, the largest cladoceran (0.65 mm mean length), was only slightly larger than the smallest copepod, *Cyclops*, while *Holopedium* (0.41 mm) and *Bosmina* (0.29 mm) were considerably smaller than all other zooplankton with the exception of unidentified immature cladocerans, which were too small to measure.

Spawning Habitat Assessment

The two main tributaries flowing into Afognak Lake, Hatchery (9,916 m^2) and Egg Take (3,448 m^2) Creeks, were estimated to be capable of supporting 13,364 spawning sockeye salmon (male and female, combined; Table 10). The remaining tributaries surveyed were estimated to be capable of supporting an additional 1,933 spawning sockeye salmon, resulting in a total tributary capacity of 15,297 spawners. While we were unable to estimate the total amount of spawning habitat within Afognak Lake, we conducted three aerial surveys of the lake shoal on 26 August, 6 September, and 21 September, 2005. The peak survey was 21 September, when we counted 770 sockeye salmon spawning.

DISCUSSION

Smolt Assessment

Prior to conducting this study, we designed and conducted a feasibility study in 2003 based on results from smolt studies conducted on the Afognak River in 1990 and 1991 (Honnold and Schrof 2004). For the pilot study, we used a different type of smolt trap than the one used in 1990 and 1991, and set it close to the middle of the river where water flow and velocity were greater. We made these changes because smolt estimates in both 1990 and 1991 seem to have been much too low, based on what we felt were reasonable survival assumptions. These changes appeared to work, since mean trap efficiency was 19.9% in 2003. In 2004, we fished the same smolt trap in approximately the same location and obtained a mean trap efficiency of 18.6% (Schrof and Honnold 2005). In 2005, the trap was placed in the same location and, despite the very low water levels, provided a good overall efficiency of 14.9%. Although the efficiency in trapping dropped slightly in 2005, the results still suggest that reliable comparisons of annual smolt production can be made.

We calculated the number of smolt that would be expected to emigrate in 2005 based on survival assumptions applied to the 2002 and 2003 escapements. We projected that the 2002 escapement of 19,520 adults would produce about 359,000 smolt and the 2003 escapement of 27,766 adults would produce approximately 510,000 smolt (Schrof and Honnold 2005; Table 11). Apportioning these smolt estimates by average age (93.0% age-1. and 7.0% age-2.) resulted in emigrations of 25,000 age-2. smolt (brood year 2002) and 475,000 age-1. smolt (brood year 2003) in 2005. Thus, approximately 500,000 smolt were expected to emigrate from the system in 2005. The projection was about 11% (60,000 smolt) lower than our 2005 mark-recapture estimate of 560,000 smolt, but was within the 95% CI range of about 487,000 to 634,000 smolt.

The 2005 emigration was dominated by age-1. smolt (93.0%) with a small portion of age-2. making up the remainder (7.0%). Similarly the age composition from the 2005 escapement was made up of 95% age-1. fish (Appendix A). We observed a similar trend in the 2004 emigration, although the age-1. smolt made up a slightly smaller component of the population (90.1%; Schrof and Honnold 2005). Typically, systems that produce a greater proportion of age-1. smolt generally have favorable freshwater rearing conditions. Increased proportions of older smolt could result from decreased lake productivity or the presence of more juvenile salmon than the system is able to support (Barnaby 1944; Krokhin 1957; Burgner 1964; Foerster 1968; Koenings et al. 1993). When the juvenile population begins to exceed the rearing capacity of a system, a greater proportion of the population must spend two or more years in freshwater before growing large enough to transform into smolt (Honnold and Schrof 2004). Based on the dominance (93.0%) of age-1. smolt emigrating from Afognak Lake in 2005, freshwater rearing capacity has not been exceeded and was able to support the juvenile population produced from recent escapements.

Age, weight, and length data for the 2005 smolt emigration also suggest that rearing conditions in Afognak Lake were not being exceeded (Table 4). Mean size and condition of age-1. smolt sampled in 2005 (n=1,248; 3.9 g, 76.8 mm, 0.84 K) demonstrated that they were healthy and robust. The 2005 age-1. smolt had a greater condition factor than smolt from previous years when evaluated against years with adequate sample sizes over a stratified time period, (Appendix B).

Emigration timing of sockeye salmon smolt from Afognak Lake in 2005 was similar to timing in 2004 as well as to the timing observed for smolt emigrating from Malina Lake, which is another sockeye salmon system on Afognak Island (Figure 4; Appendices C-D). Smolt emigration from both systems generally begins in mid-May, peaks early to mid-June, and is essentially over by early July. Documentation from other systems (Barnaby 1944; Krogius and Krokhin 1948; Burgner 1962), has indicated that older and larger smolt tend to migrate earlier from their rearing system.

Limnological Assessment

Seasonal water chemistry (pH, alkalinity) showed little variation in Afognak Lake in the 2005 sampling, which is consistent with results from the past five years (2000-2004; Appendix E). Silica, the only dissolved nutrient measured in 2005, was similar to concentrations observed in 2004. The 2005 seasonal mean algal standing crop (chl *a*) of Afognak Lake (1.60 µg L^{-1}) is consistent with prior years of data collection from Afognak Lake which is comparable to oligotrophic Alaska lakes, in that they typically have chl *a* concentrations below 1.5 µg L^{-1} (Honnold et al. 1996). Levels measured during 1990-1998 ranged from 0.10 to 4.20 µg L^{-1}

(Schrof and Honnold 2003). However, chl *a* concentrations measured at other lakes on Afognak Island also tend to show a high degree of variation (Schrof and Honnold 2003).

Seasonal phosphorus levels in 2005 showed a slight elevation as compared to prior years of data collection, while the total nitrogen levels were closer to what was observed in the past three years (Appendix F). The total nitrogen and phosphorus ratio of 45.4:1 in 2005 reflects a greatly improved ratio from 2004 when the ratio was 112.2:1, although optimum TN:TP ratios range from 10:1 to 20:1 (Honnold et al. 1996; Honnold and Schrof 2001).

Seasonal mean zooplankton abundance and biomass estimates at Station 2 were about 35% less than estimates from Station 1 (Table 9), which is likely due to Station 2 being closer to the lake outlet. Lake water residence time is estimated to be only 0.4 years, so rapid lake flushing may remove zooplankton quicker than they can be replenished through reproduction (White et al. 1990; Schrof and Honnold 2005). Rapid flushing may also affect nutrient availability for phytoplankton, which could affect zooplankton production. From 1988-1997, zooplankton tows were made at both stations, but in 1998, Station 2 was no longer sampled (Appendix G). During the time period both stations were sampled, zooplankton numbers were 8% to 100% lower at Station 2 than Station 1.

Since the zooplankton community serves as the primary forage base in lakes for juvenile sockeye salmon, total zooplankton abundance and biomass are often estimated to assess juvenile sockeye salmon production potential (Koenings et al. 1987). Overall, zooplankton abundance in 2005 was higher than estimates obtained in recent years (Table 9; Appendix G). However, juvenile sockeye salmon prefer to eat cladocerans rather than copepods, so cladoceran abundance is a better indicator of evaluating sockeye salmon forage (Koenings et al. 1987; Kyle 1996).

While the abundance of the cladoceran *Daphnia* was much less than that observed in 2004, which may have been an anomalous year, its abundance in 2005 was still higher than that observed in three of the past four years at station 1(Table 9; Appendix G). This is encouraging, since *Daphnia* are the primary prey for juvenile sockeye salmon and their increase probably indicates a lack of excessive foraging by juvenile sockeye salmon (Kyle 1996; Honnold and Schrof 2001). A similar trend was also seen for the cladoceran *Holopedium*, while the cladoceran *Bosmina* has fluctuated in abundance during this time period. *Bosmina* are more difficult for juvenile salmon to locate and eat due to its small size (Koenings and Kyle 1997). *Bosmina* are about half the size of *Daphnia* and about two thirds the size of *Holopedium.* Copepods are usually not as important as a juvenile salmon food item when cladocerans are present, and copepod abundance was considerably less than cladoceran abundance in 2004. Mean densities of *Diaptomus* at Stations 1 and 2 were generally much less than those observed during the period 1991-2004, while densities of *Epischura* and *Cyclops* were generally similar to those observed during that same time period. All three identified copepods were slightly smaller in size in 2005 compared to historical averages.

Spawning Habitat Assessment

Nelson et al. (2005) recently analyzed data as part of an escapement goal review on sockeye salmon production at Afognak Lake. As part of this review, historical spawning habitat data for sockeye salmon in Afognak Lake suggested that available shoreline spawning habitat could support 36,000 to 71,000 spawners (average, 50,000 spawning adults; Appendix H). The upper end of the estimated range, 71,000 spawner, was based on a tagging study conducted in 1982, which had the second largest escapement on record (Willette 1982; Table 1). The percentage of spawners observed in the two main tributaries was applied to the total escapement estimate, and the remaining spawners were assumed to be on the lake shoals. This assumption does not necessarily correlate with available spawning habitat.

The escapement goal evaluation determined that Afognak Lake sockeye salmon production is limited by available rearing habitat, rather than by spawning habitat. After evaluating the data from the shoreline surveys, coupled with the low sockeye salmon escapement into Afognak Lake in 2005, we decided to evaluate the lake shore habitat for an additional year (2006) for spawning and escapement data to further the analysis. Since our shoreline evaluation was based on actual observations of spawning salmon, we were unable to reasonably estimate the spawning habitat (770 spawners). The results of the 2005 and 2006 data on the Afognak Lake shore habitat will be reported in the final report.

The habitat assessments on Eggtake, Hatchery and the remaining inlet creeks were conducted using a different approach to determine spawning habitat for sockeye salmon than the lake shore assessment. Creek habitats were assessed by the established criteria outlined in the methods as opposed to the lake shoal data, which was determined by actual spawning activity. The criteria used for the tributary assessments were less subjective because the evaluation did not require spawning salmon. White et. al (1990) reported a similar spawning habitat assessment in the tributaries which had data that closely matched our 2005 tributary results (Appendix H). However, we were unable to determine how the spawning habitat estimates were calculated by White et. al (1990) because their methods were not reported for comparison to our study. Regardless, we feel the available spawning habitat in the Afognak Lake tributaries of 15,000 sockeye salmon is a reasonable estimate. Additional years of habitat and spawner data collection will help to generate a more accurate assessment of potential spawning habitat along the lake shore.

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Table 1. Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978-2005.

		Harvest				
Year	Escapement	Commercial[a]	Subsistence[b]	Sport[c]	Total	Total Run
1978	52,701	3,414	1,632	524	5,570	58,271
1979	82,703	2,146	2,069	524	4,739	87,442
1980	93,861	28	3,352	524	3,904	97,765
1981	57,267	16,990	3,648	524	21,162	78,429
1982	123,055	21,622	3,883	524	26,029	149,084
1983	40,049	4,349	3,425	524	8,298	48,347
1984	94,463	6,130	3,121	524	9,775	104,238
1985	53,563	1,980	6,804	524	9,308	62,871
1986	48,328	2,585	3,450	524	6,559	54,887
1987	25,994	1,323	2,767	524	4,614	30,608
1988	39,012	14	2,350	524	2,888	41,900
1989	88,825	0	3,859	524	4,383	93,208
1990	90,666	22,149	4,469	524	27,142	117,808
1991	88,557	47,237	5,899	524	53,660	142,217
1992	77,260	2,196	4,638	600	7,434	84,694
1993	71,460	1,848	4,580	524	6,952	78,412
1994	80,570	17,362	3,329	524	21,215	101,785
1995	100,131	67,665	4,390	524	72,579	172,710
1996	101,718	106,141	11,023	258	117,422	219,140
1997	132,050	10,409	12,412	535	23,356	155,406
1998	66,869	26,060	4,690	718	31,468	98,337
1999	95,361	34,420	5,628	237	40,285	135,646
2000	54,064	14,124	7,572	364	22,060	76,124
2001	24,271	0	4,720	169	4,889	29,160
2002	19,520	0	1,279	41	1,320	20,840
2003	27,766	0	604	0	604	28,370
2004	15,181	0	567	10	577	15,758
2005	21,577	356	656	nd	1,012	22,589

[a] Statistical fishing section 252-34 (Afognak Bay).
[b] Data from ADF&G subsistence catch database.
[c] Data from ADF&G Sport Fish Division statewide harvest survey (SWHS) for 1992, 1996-2004; SWHS data for other years did not have enough respondents to provide reliable estimates. Four years with reliable data were averaged and entered for years with no data.
nd - no data available

Table 2. Sockeye salmon smolt counts, number of samples collected, mark-recapture counts, and trap efficiency ratios from trapping at Afognak River, 2005.

Date	Catch Daily	Catch Cumulative	Dye Test Period Cumulative	AWL Sample Cumulative	Number Marked Releases	Marked Recoveries Cumulative	Trap Efficiency (%)
10-May	576	576					
11-May	349	925		40			
12-May	1,324	2,249		73			
13-May	1,407	3,656		113			
14-May	2,645	6,301					
15-May	2,589	8,890		153			
16-May	1,809	10,699		193			
17-May	2,939	13,638		233	489	45	
18-May	3,036	16,674		273		70	
19-May	2,481	19,155		313		70	
20-May	2,990	22,145				70	
21-May	5,081	27,226	27,226			70	14.3%
22-May	1,781	29,007		353			
23-May	1,756	30,763		393	518	20	
24-May	5,365	36,128		433		42	
25-May	2,536	38,664		473		43	
26-May	2,189	40,853	13,627	513		43	8.3%
27-May	2,317	43,170			482	30	
28-May	3,873	47,043				43	
29-May	801	47,844		553		44	9.1%
30-May	1,568	49,412		593			
31-May	1,572	50,984		633			
1-Jun	2,607	53,591		673			
2-Jun	1,216	54,807		713			
3-Jun	933	55,740					
4-Jun	323	56,063					
5-Jun	0	56,063	15,210				
6-Jun	67	56,130					
7-Jun	428	56,558		793			
8-Jun	840	57,398		833			
9-Jun	487	57,885		873			
10-Jun	1,484	59,369		913			
11-Jun	2,761	62,130			368	48	
12-Jun	3,311	65,441				103	28.0%
13-Jun	2,283	67,724		953			
14-Jun	1,140	68,864		993			
15-Jun	1,721	70,585		1,033			
16-Jun	928	71,513		1,073			
17-Jun	791	72,304		1,113			

-continued-

Table 2. (page2 of 2)

Date	Catch Daily	Catch Cumulative	Dye Test Period Cumulative	AWL Sample Cumulative	Number Marked Releases	Marked Recoveries Cumulative	Trap Efficiency (%)
18-Jun	827	73,131					
19-Jun	46	73,177		1,153			
20-Jun	177	73,354		1,193			
21-Jun	45	73,399		1,233			
22-Jun	100	73,499					
23-Jun	76	73,575		1,273			
24-Jun	50	73,625		1,313			
25-Jun	14	73,639					
26-Jun	27	73,666					
27-Jun	31	73,697	17,634				
28-Jun	Trap pulled				Average Trap Efficiency=		14.9%

Table 3. Estimated age composition of the Afognak Lake sockeye salmon smolt sampled in each dye test period, 2005.

Stratum	Sample Size		Age 1	Age 2	Age 3	Total
1	313	Percent	81.8	18.2	0	100.0
5/10-5/21		Numbers	256	57	0	313
2	200	Percent	96.5	3.5	0	100.0
5/22-5/26		Numbers	193	7	0	200
3	200	Percent	100	0	0	100.0
5/27-6/5		Numbers	200	0	0	200
4	600	Percent	99.8	0.2	0	100.0
6/6-6/27		Numbers	599	1	0	600
Total	1,313					

Table 4. Length, weight, and condition of sockeye salmon smolt from the Afognak River, 2005.

		Weight (g)		Length (mm)		Condition	
Statistical Week	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Age 1.							
20	158	2.8	0.03	71.7	0.25	0.75	0.005
21	172	3.0	0.03	72.6	0.22	0.79	0.006
22	199	3.0	0.02	72.2	0.18	0.79	0.004
23	120	3.1	0.03	73.1	0.21	0.80	0.003
24	239	4.4	0.04	78.3	0.20	0.91	0.004
25	240	5.2	0.03	83.2	0.17	0.90	0.003
26	120	5.6	0.05	84.8	0.23	0.92	0.004
Totals	1,248	3.9	0.03	76.8	0.16	0.84	0.002
Age 2.							
20	35	4.0	0.09	80.9	0.45	0.75	0.010
21	28	4.4	0.21	81.5	1.23	0.80	0.012
22	1	3.9	0.00	78.0	0.00	0.82	0.000
24	1	6.4	0.00	97.0	0.00	0.70	0.000
Totals	65	4.2	0.11	81.3	0.63	0.77	0.008

Table 5. Population estimate of the sockeye salmon smolt emigration from Afognak Lake, 2005.

Stratum (h)	Starting Date	Ending Date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Estimate (U_h)	Variance var (U_h)	95% Confidence Interval lower	upper
1	5/10	5/21	27,226	489	70	184,879	4.05E+08	145,443	224,314
2	5/22	5/26	13,627	518	43	155,259	4.89E+08	111,932	198,587
3	5/27	6/5	15,210	482	44	158,499	4.94E+08	114,948	202,050
4	6/6	6/27	17,634	368	103	61,593	2.58E+07	51,640	71,546
Total						560,230	1.41E+09	486,554	633,906
						SE=	37,590		

Table 6. The Afognak Lake sockeye salmon smolt emigration estimate based on percents by age class and dye test period, 2005.

Stratum	Dye Test Period	Age 1.	Age 2.	Age 3.	Total
1	(5/10-5/21)	151,231	33,648	0	184,879
2	(5/22-5/26)	149,825	5,434	0	155,259
3	(5/27-6/5)	158,499	0	0	158,499
4	(6/6-6/27)	61,470	123	0	61,593
Total		521,025	39,205	0	560,230
		93.0%	7.0%	0.0%	100.0%

Table 7. General water chemistry and algal pigment concentrations at 1 m water depth, station 1, Afognak Lake 2005.

Date	pH (units)	Alkalinity (mg L^{-1})	Silicon (µg L^{-1})	Chlorophyll *a* (µg L^{-1})
17-May	6.9	9.8	3,271.8	0.96
14-Jun	6.8	10.0	2,963.2	1.28
14-Jul	6.8	11.0	2,554.7	0.96
8-Aug	6.7	12.5	2,465.1	1.28
20-Sep	6.7	11.5	2,565.6	1.28
Average	6.8	11.0	2,764.1	1.15
STDEV	0.1	1.1	342.8	0.18

Table 8. Seasonal phosphorus and nitrogen concentrations at 1 m water depth, station 1, Afognak Lake, 2005.

Date	Total filterable-P ($\mu g\ L^{-1}$)	Filterable reactive-P ($\mu g\ L^{-1}$)	Total-P ($\mu g\ L^{-1}$)	Ammonia ($\mu g\ L^{-1}$)	Total Kjeldahl Nitrogen ($\mu g\ L^{-1}$)	Nitrate + Nitrite ($\mu g\ L^{-1}$)	Total Nitrogen ($\mu g\ L^{-1}$)	TN:TP ratio
17-May	6.3	3.0	9.1	3.5	238.0	90.9	328.9	242.8
14-Jun	5.3	2.2	16.3	3.5	142.0	61.9	203.9	205.2
14-Jul	4.6	2.6	14.5	4.1	127.0	21.0	148.0	126.0
8-Aug	13.6	9.0	11.7	3.1	166.0	7.4	173.4	42.7
20-Sep	8.3	1.1	5.3	7.9	132.0	21.2	153.2	308.4
Average	7.6	3.6	11.4	4.4	161.0	40.5	201.5	185.0
STDEV	3.6	3.1	4.4	2.0	45.6	34.8	74.5	103.3

Table 9. Weighted mean zooplankton density, biomass, and size by station from Afognak Lake, 2005.

Station	*n*		*Epischura*	*Diaptomus*	*Cyclops*	Other Copepods	*Bosmina*	*Daphnia*	*Holopedium*	Other Cladocerans	Total Copepods	Total Cladocerans	Total all zooplankton
1	5	density (no. m^{-2})	21,369	1,592	8,238	20,722	82,409	4,979	2,027	1,550	51,922	90,965	142,887
		%	15.0%	1.1%	5.8%	14.5%	57.7%	3.5%	1.4%	1.1%	36.3%	63.7%	100.0%
		biomass (mg m^{-2})	58.6	4.0	10.0	1.8	65.5	6.7	3.0	0.8	74.4	76.0	150.4
		%	38.9%	2.7%	6.6%	1.2%	43.6%	4.5%	2.0%	0.5%	49.5%	50.5%	100.0%
		size (mm)	0.79	0.83	0.63	0.56	0.30	0.57	0.43				
2	5	density (no. m^{-2})	22,282	0	2,850	13,450	49,992	815	900	350	38,583	52,057	90,640
		%	24.6%	0.0%	3.1%	14.8%	55.2%	0.9%	1.0%	0.4%	42.6%	57.4%	100.0%
		biomass (mg m^{-2})	59.9	0.0	3.9	2.3	37.2	2.0	1.0	0.0	66.0	40.2	106.2
		%	56.4%	0.0%	3.7%	2.1%	35.1%	1.8%	0.9%	0.0%	62.2%	37.8%	100.0%
		size (mm)	0.79	0.64	0.63	0.56	0.29	0.73	0.38				
1 & 2		density (no. m^{-2})	21,826	796	5,544	17,086	66,201	2,897	1,464	950	45,252	71,511	116,764
Averaged		%	18.7%	0.7%	4.7%	14.6%	56.7%	2.5%	1.3%	0.8%	38.8%	61.2%	100.0%
		biomass (mg m^{-2})	59.2	2.0	7.0	2.0	51.4	4.4	2.0	0.4	70.2	58.1	128.3
		%	46.1%	1.6%	5.4%	1.6%	40.0%	3.4%	1.5%	0.3%	54.7%	45.3%	100.0%
		size (mm)	0.79	0.73	0.63	0.56	0.29	0.65	0.41				

Table 10. Available sockeye salmon spawning habitat estimates of Afognak Lake tributaries as determined by creek size and usable habitat in 2005.

Spawning Location	Total Length (m)	Total Width (m)	Total Habitat (m2)	Usable Habitat (%)	Usable Habitat (m2)	Spawning Capacity
Hatchery Creek	3,189	114	23,050	43%	9,916	9,916
Egg Take Creek	1,300	40	8,676	40%	3,448	3,448
Minor Creeks	3,998	50	9,121	21%	1,933	1,933
Total	8,487	204	40,846	37%	15,297	15,297

Table 11. Afognak Lake sockeye salmon theoretical production of eggs, emergent fry, and smolt by age from brood years 2002 and 2003 and predicted smolt emigration in 2005.

Production		Brood Year		Total
Parameter	Assumption	2002	2003	
Escapement		19,520	27,766	
Females spawning	1:1 sex ratio	9,760	13,883	
Deposited Eggs	2,500 per female[a]	24,400,000	34,707,500	
Emergent Fry	7% egg-to-fry survival[b]	1,708,000	2,429,525	
Smolt	21% fry-to-smolt survival[c]	358,680	510,200	
Estimated 2005 smolt abundance	93.0% age-1., 7.0% age-2.[d]	25,108	474,486	499,594

[a]Roelofs (1964)

[b]Average from Drucker (1970) and Koenings and Kyle (1997)

[c]Koenings and Kyle (1997)

[d] See Table 6 for 2005 mark-recapture estimates of smolt abundance

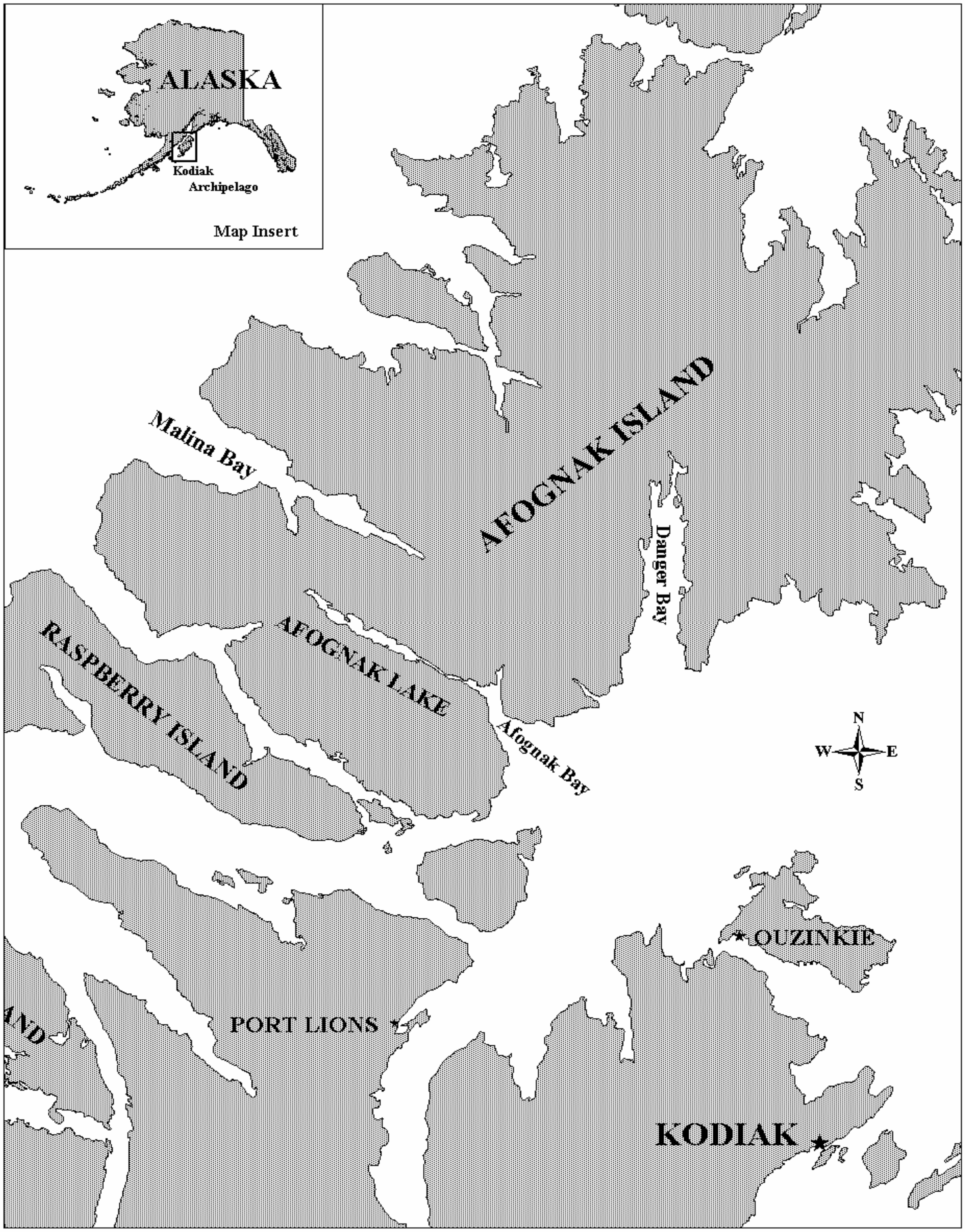


Figure 1. This map displays the location of Kodiak City, and the villages of Port Lions, and Ouzinkie and their proximity to the Afognak Lake drainage on Afognak Island.

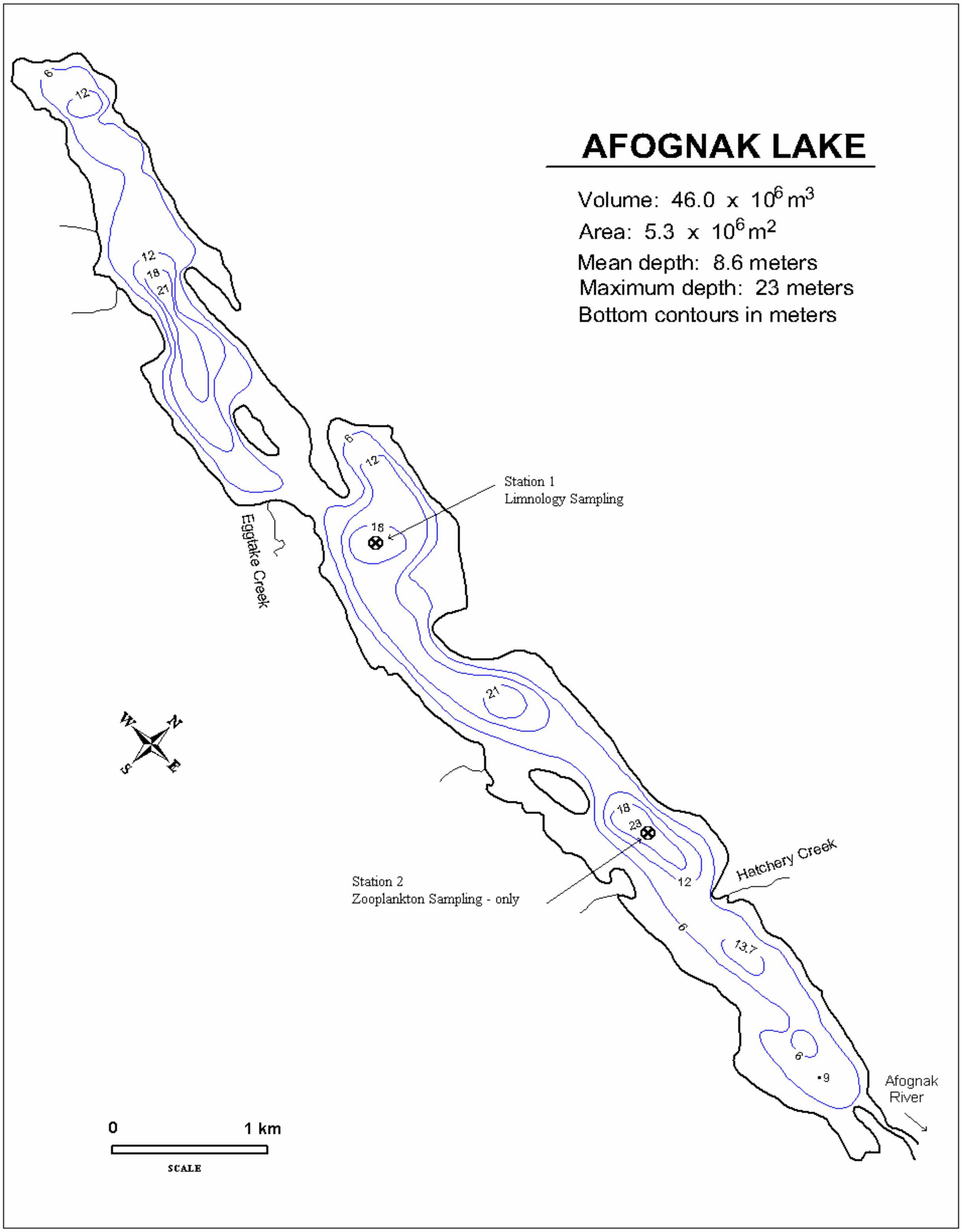


Figure 2. Bathymetric map showing the limnology and zooplankton stations on Afognak Lake.

Figure 3. The smolt trapping system set up in the Afognak River, 2005.

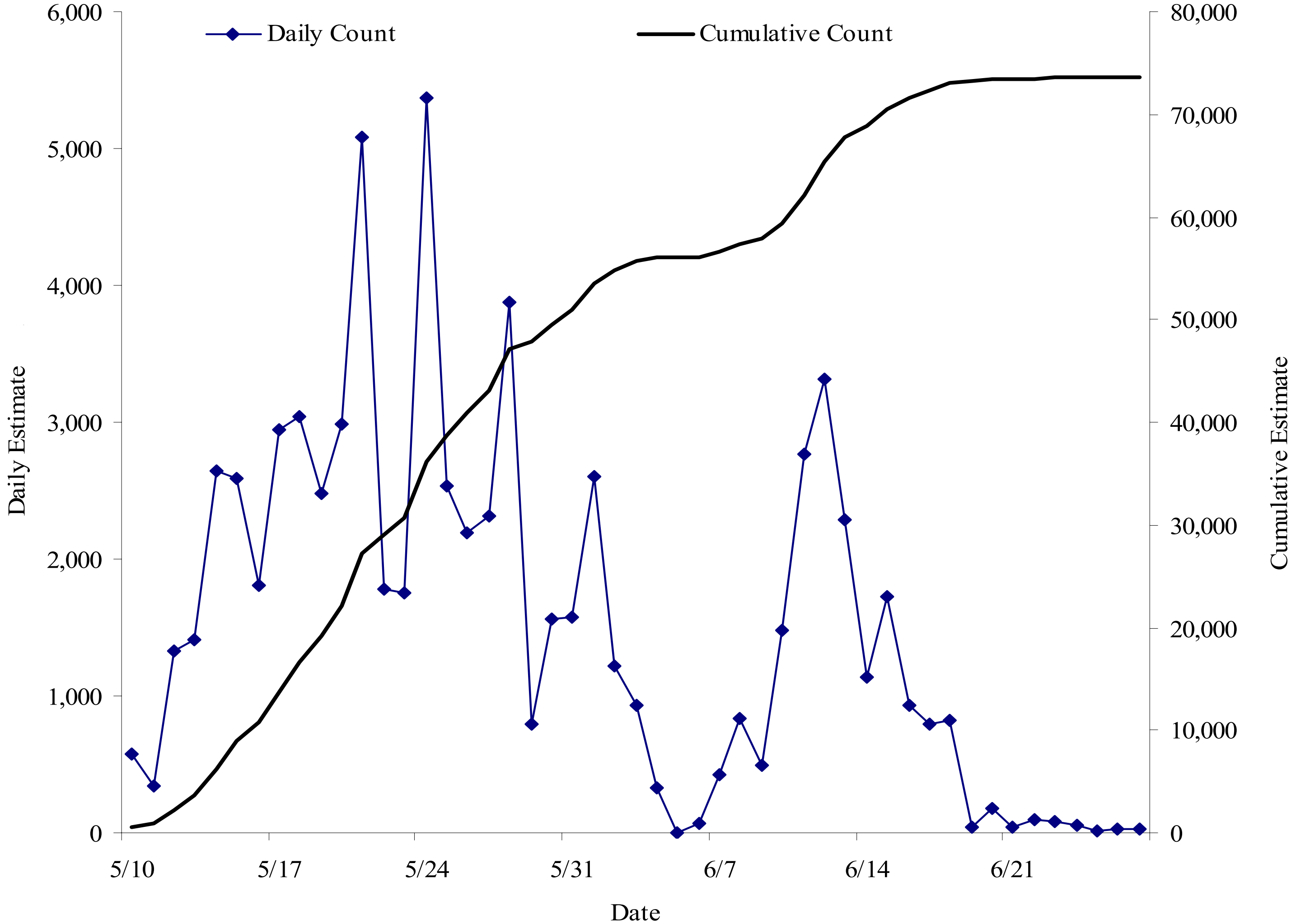


Figure 4. Daily and cumulative sockeye salmon smolt trap catch estimates by day from 10 May to 27 June in the Afognak River, 2005.

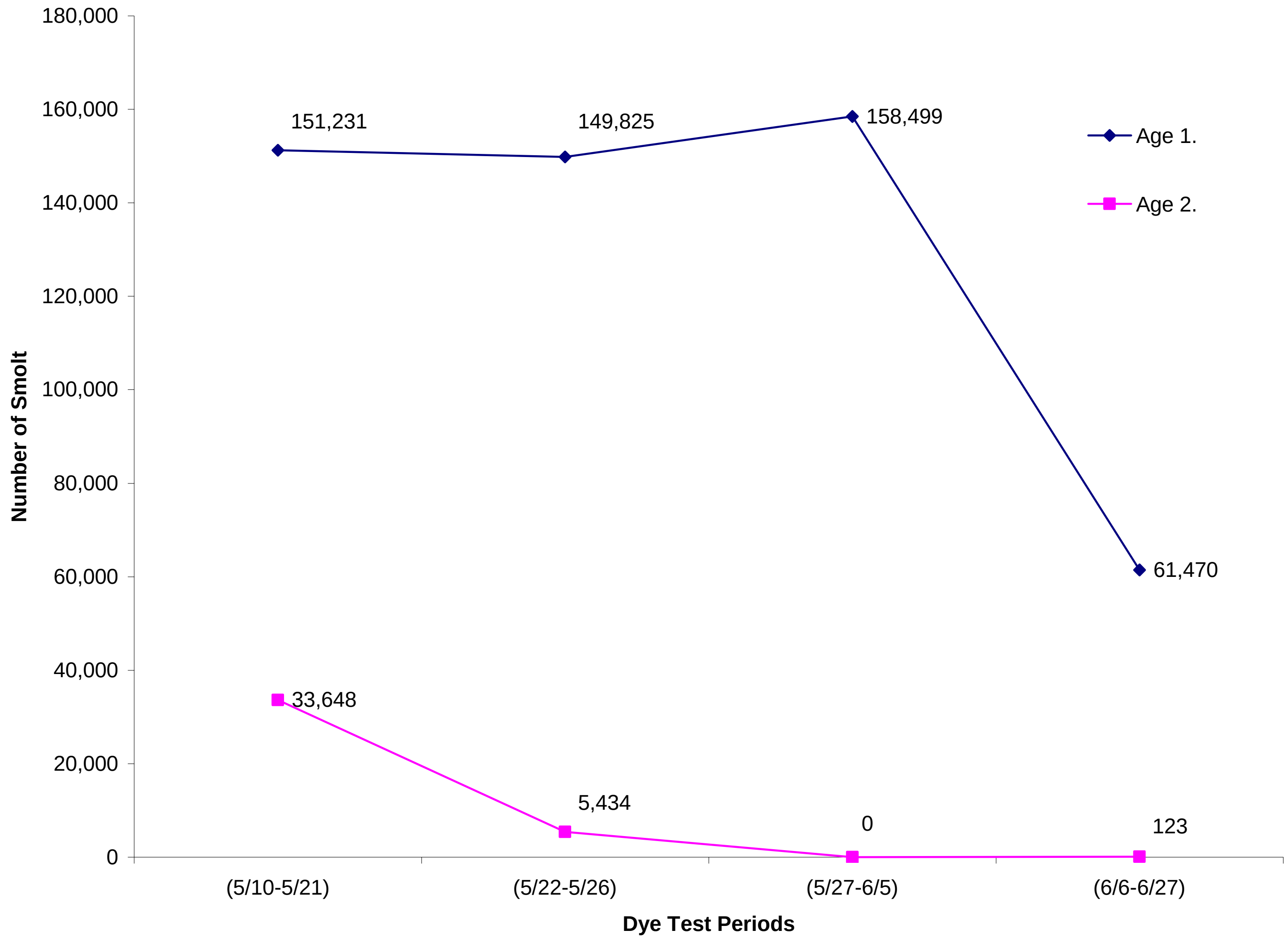


Figure 5. Afognak Lake sockeye salmon smolt sampled during the emigration by age class and dye test period, 2005.

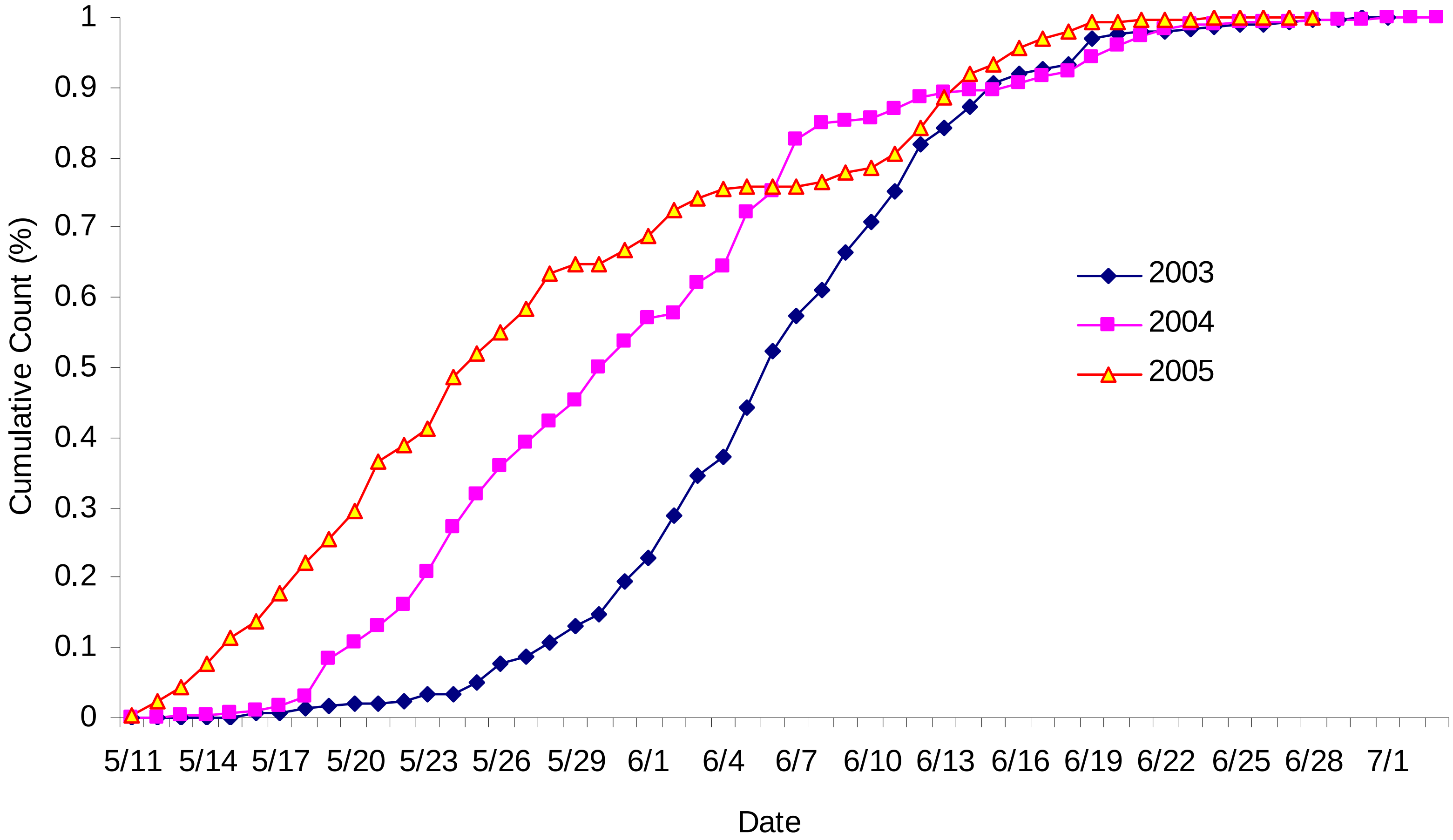
Appendix A. Estimated age composition of the Afognak Lake sockeye salmon escapement 1987-2005.

	Sample		Ages									
Year	Size		1.1	1.2	2.1	1.3	2.2	3.1	1.4	2.3	3.2	3.3
1987	281	Numbers	1,695	9,797	284	9,609	1,131	0	0	3,863	0	0
		Percent	6.4	37.0	1.1	36.3	4.3	0.0	0.0	14.6	0.0	0.0
1988	933	Numbers	263	23,059	824	9,773	4,488	0	0	429	0	0
		Percent	0.7	59.1	2.1	25.1	11.5	0.0	0.0	1.1	0.0	0.0
1989	1,088	Numbers	13,288	13,404	3,135	35,165	16,314	0	0	7,519	0	0
		Percent	15.0	15.1	3.5	39.6	18.4	0.0	0.0	8.5	0.0	0.0
1990	1,053	Numbers	597	42,314	553	20,518	7,754	0	261	18,613	0	0
		Percent	0.7	46.7	0.6	22.6	8.6	0.0	0.3	20.5	0.0	0.0
1991	1,062	Numbers	295	13,054	196	67,805	3,101	0	0	4,106	0	0
		Percent	0.3	14.7	0.2	76.6	3.5	0.0	0.0	4.6	0.0	0.0
1992	1,025	Numbers	16,362	17,115	7,681	23,096	2,938	90	394	9,526	61	0
		Percent	21.2	22.2	9.9	29.9	3.8	0.1	0.5	12.3	0.0	0.0
1993	852	Numbers	11,837	7,634	12,318	21,667	8,818	53	0	8,965	163	0
		Percent	16.6	10.7	17.2	30.3	12.3	0.1	0.0	12.5	0.2	0.0
1994	840	Numbers	7,703	24,648	3,337	28,385	8,316	125	61	7,708	64	0
		Percent	9.6	30.6	4.1	35.2	10.3	0.2	0.1	9.6	0.1	0.0
1995	848	Numbers	2,281	21,788	837	56,367	10,773	0	149	7,776	0	0
		Percent	2.3	21.8	0.8	56.3	10.8	0.0	0.1	7.8	0.0	0.0
1996	1,119	Numbers	16,340	9,398	2,184	44,744	2,095	0	185	26,427	80	0
		Percent	16.0	9.2	2.1	44.0	2.1	0.0	0.2	26.0	0.1	0.0
1997	1,168	Numbers	5,234	29,004	7,330	47,888	2,351	0	41	14,840	0	0
		Percent	4.9	27.1	6.9	44.8	2.2	0.0	0.0	13.9	0.0	0.0
1998	1,240	Numbers	13,039	5,483	5,082	31,763	7,289	134	267	3,812	0	0
		Percent	19.5	8.2	7.6	47.5	10.9	0.2	0.4	5.7	0.0	0.0
1999[a]	1,195	Numbers	661	30,350	427	6,911	30,943	72	202	5,466	456	0
		Percent	0.9	40.2	0.6	9.1	41.0	0.1	0.3	7.2	0.6	0.0
2000	1,161	Numbers	887	1,276	171	8,302	3,084	0	0	37,238	1,753	0
		Percent	1.7	2.4	0.3	15.6	5.8	0.0	0.0	70.0	3.3	0.0
2001	790	Numbers	137	2,393	833	5,473	676	1,877	0	9,328	0	0
		Percent	0.7	11.4	4.0	26.2	3.2	9.0	0.0	44.6	0.0	0.0
2002	238	Numbers	20	215	683	6,871	4,626	176	0	976	5,934	0
		Percent	0.1	1.1	3.5	35.2	23.7	0.9	0.0	5.0	30.4	0.0
2003	498	Numbers	1,148	6,273	66	233	7,141	0	0	8,229	770	3,907
		Percent	4.1	22.6	0.2	0.8	25.7	0.0	0.0	29.6	2.8	14.1
2004[b]	566	Numbers	170	6,720	25	2,888	280	0	3	4,073	0	843
		Percent	1.1	44.3	0.2	19.0	1.8	0.0	0.0	26.8	0.0	5.6
2005[c]	572	Numbers	683	2,153	136	17,697	472	0	0	280	0	843
		Percent	3.2	10.0	0.6	82.0	2.2	0.0	0.0	1.3	0.0	5.6
Average		Numbers	5,109	14,662	2,554	23,748	6,784	140	87	9,939	516	264
1987-2004		Percent	6.8	23.6	3.6	33.0	11.1	0.6	0.1	17.8	2.1	1.1

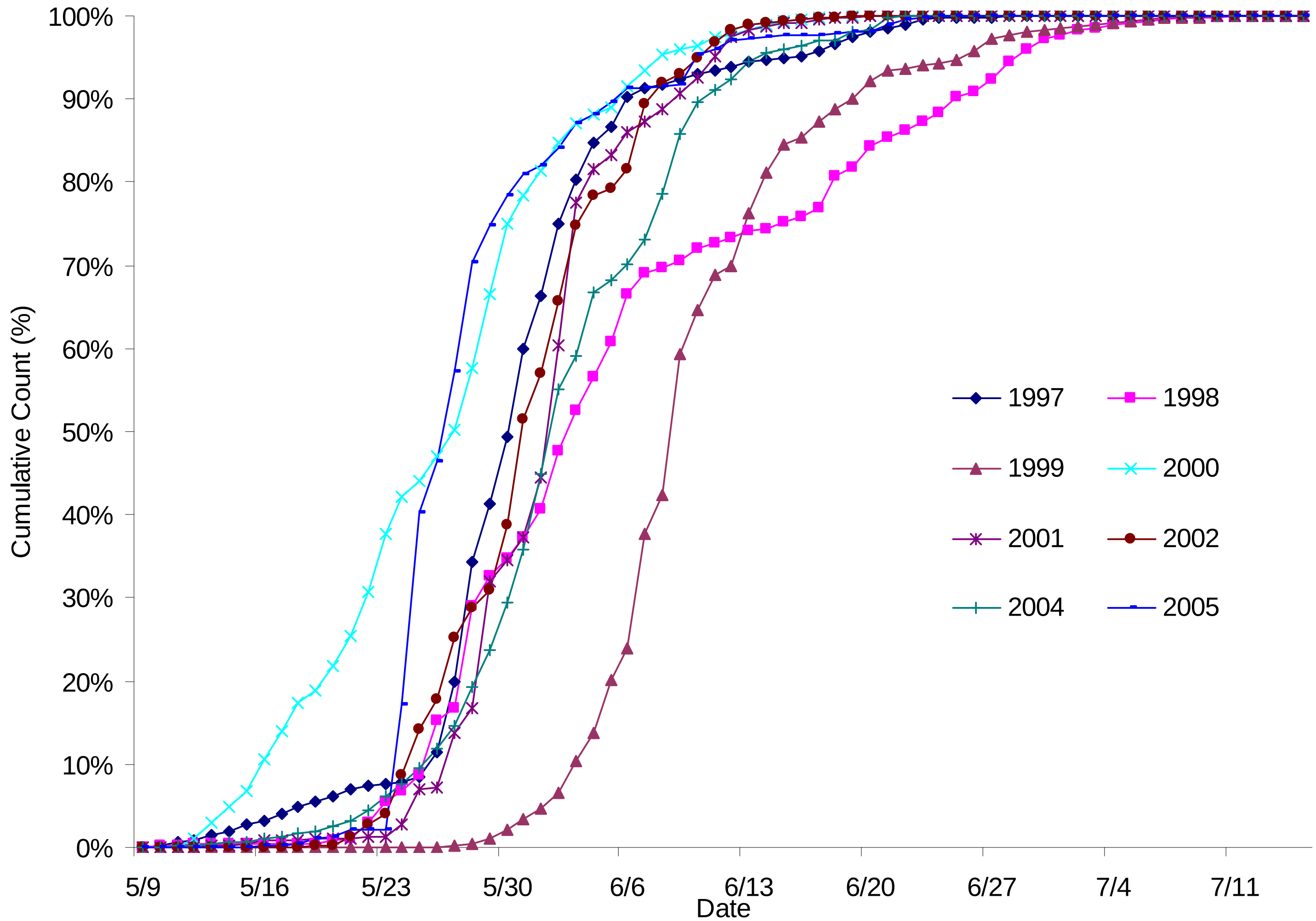
[a] In 1999, 72 (0.1%) sockeye salmon were aged 0.4.
[b] In 2004, 179 (1.2%) sockeye salmon were aged 2.4.
[c] In 2005, 157 (0.7%) sockeye salmon were age 0.3.

Appendix B. Mean weight, length, and condition coefficient by age for sockeye salmon smolt sampled at Afognak Lake, 1987-2001, and 2003-2005.

		Age-1				Age-2			
Year	Sampling Period	n	Weight (g)	Length (mm)	Condition (K)	n	Weight (g)	Length (mm)	Condition (K)
1987	8-Jun	36	3.6	74.9	0.85	186	3.6	79.3	0.86
1988	15-Jun	202	4.1	77.9	0.90	0			
1989	15-Jun	208	4.1	76.8	0.91	2	5.2	78.0	1.10
1990	May23-June 24	544	2.5	68.8	0.76	21	3.4	77.3	0.73
1991	May 13-June 26	1,895	3.1	72.9	0.78	176	3.9	78.3	0.81
1992	June 7-20	268	3.8	77.0	0.82	37	3.8	76.9	0.83
1993	May 24-30	274	3.0	72.7	0.78	21	3.3	74.8	0.79
1994	May 17-23	138	3.0	72.0	0.81	142	4.7	84.3	0.79
1995	May 31-June 13	394	2.8	69.4	0.84	5	3.6	78.8	0.74
1996	June 5-11	54	4.6	80.9	0.87	339	4.8	81.6	0.88
1997	May 24-30	76	4.3	81.7	0.78	122	4.4	82.1	0.79
1998	May 24-30	116	2.6	66.4	0.82	46	6.6	88.0	0.90
1999	May 31-June 6	96	2.8	74.6	0.66	98	2.1	66.6	0.69
2000	May 31-June 13	84	4.9	81.5	0.89	100	5.6	85.3	0.89
2001	June 11-13	44	7	90.1	0.93	17	5.8	85.6	0.92
2003	May 12-July 3	1031	4.2	79.1	0.82	383	4.2	81.4	0.77
2004	May 11-July 3	1370	3.6	75.7	0.80	81	3.6	78.7	0.74
2005	May 10-June 27	1248	3.9	76.8	0.84	65	4.2	81.3	0.77



Appendix C. Sockeye salmon smolt emigration timing from Afognak Lake, 2003-2005.



Appendix D. Sockeye salmon smolt emigration timing from Malina Lakes, 1997-2002, and 2004-2005.

Appendix E. General water chemistry and algal pigment concentrations at 1 m water depth, station 1, Afognak Lake, 2000-2005.

Date	pH (units)	Alkalinity (mg L^{-1})	Silicon (µg L^{-1})	Chlorophyll *a* (µg L^{-1})
2000	7.10	8.70	n/a	2.43
2001	7.18	10.10	n/a	2.37
2002	7.20	10.15	n/a	1.36
2003	6.87	9.75	n/a	1.20
2004	6.89	11.40	2764.08	1.15
2005	6.79	10.90	2700.83	1.60
Average	7.01	10.17	2732.45	1.69
STDEV	0.18	0.94	44.73	0.58

Appendix F. Seasonal phosphorus and nitrogen concentrations at 1 m water depth, in Afognak Lake 2000-2005.

Date	Total filterable-P ($\mu g\ L^{-1}$)	Filterable reactive-P ($\mu g\ L^{-1}$)	Total-P ($\mu g\ L^{-1}$)	Ammonia ($\mu g\ L^{-1}$)	Total Kjeldahl Nitrogen ($\mu g\ L^{-1}$)	Nitrate + Nitrite ($\mu g\ L^{-1}$)	Total Nitrogen ($\mu g\ L^{-1}$)	TN:TP ratio
5/15/2000	4.9	1.3	13.3	30.5	25.4	133.7	159.1	26.5
6/20/2000	3.8	4.5	6.0	22.7	na	49.3	49.3	18.2
8/2/2000	3.9	0.5	14.8	6.5	47.2	60.3	107.5	16.1
9/20/2000	2.0	1.9	8.3	31.3	na	44.4	44.4	11.8
10/11/2000	0.9	0.8	5.2	5.9	96.9	69.7	166.6	71.0
2000 Avg.	3.1	1.8	9.5	19.4	56.5	71.5	105.4	28.7
5/7/2001	8.8	10.4	2.4	8.5	77.5	82.7	160.2	147.8
6/10/2001	6.3	11.8	9.3	2.5	111.8	61.8	173.6	41.3
7/16/2001	0.8	1.5	4.7	2.7	128.0	14.0	142.0	66.9
8/14/2001	13.8	16.4	15.6	1.0	118.3	9.1	127.4	18.1
9/13/2001	2.2	1.0	7.2	8.4	136.7	22.1	158.8	48.8
2001 Avg.	6.4	8.2	7.8	4.6	114.5	37.9	152.4	64.6
5/15/2002	8.2	4.2	7.6	1.7	127.4	53.1	180.5	52.6
6/27/2002	5.3	4.0	8.9	7.2	154.0	18.2	172.2	42.8
8/12/2002	0.8	1.0	3.7	4.1	121.8	9.8	131.6	78.8
10/10/2002	3.8	4.0	5.5	6.5	121.8	25.5	147.3	59.3
2002 Avg.	4.5	3.3	6.4	4.9	131.3	26.7	157.9	58.4
5/20/2003	1.7	2.1	7.9	4.3	151.0	93.1	244.1	68.4
6/24/2003	1.6	1.8	9.9	5.5	145.0	51.7	196.7	44.0
8/5/2003	3.3	3.2	3.2	4.6	124.0	39.3	163.3	113.0
9/25/2003	2.0	1.4	4.9	8.3	126.0	33.5	159.5	72.1
2003 Avg.	2.2	2.1	6.5	5.7	136.5	54.4	190.9	74.4
5/10/2004	4.0	2.2	4.8	6.5	306.0	81.8	387.8	178.9
6/7/2004	9.8	2.3	11.5	6.6	38.0	100.4	138.4	26.6
7/6/2004	1.6	0.8	7.8	6.9	128.0	58.3	186.3	52.9
8/11/2004	3.6	2.7	2.7	9.4	236.0	20.2	256.2	210.1
9/20/2004	2.6	1.8	4.3	13.0	137.0	43.0	180.0	92.7
2004 Avg.	4.3	2.0	6.2	8.5	169.0	60.7	229.7	112.2
5/17/2005	6.3	3.0	9.1	3.5	238.0	90.9	328.9	80.0
6/14/2005	5.3	2.2	16.3	3.5	142.0	61.9	203.9	27.7
7/14/2005	4.6	2.6	14.5	4.1	127.0	21.0	148.0	22.6
8/8/2005	13.6	9.0	11.7	3.1	166.0	7.4	173.4	32.8
9/20/2005	8.3	1.1	5.3	7.9	132.0	21.2	153.2	64.0
2005 Avg.	7.6	3.6	11.4	4.4	161.0	40.5	201.5	45.4

Appendix G. Weighted mean zooplankton density, biomass, and size for Afognak Lake, stations 1 and 2, 1987-2005.

Station		*Epischura*			*Diaptomus*			*Cyclops*			*Bosmina*			*Daphnia*			*Holopedium*			TOTALS	
1	No.	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass
Year	Samples	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)
1987	4	28,835	100	0.91	173	1	1.01	4,127	6	0.65	138,370	134	0.33	3,218	4	0.54	2,574	6	0.52	177,297	251
1988	4	22,360	77	0.91	0	0		3,185	5	0.69	106,462	104	0.33	962	2	0.71	1,228	3	0.53	134,197	191
1989	5	16,322	71	0.99	0	0		3,663	5	0.66	69,638	59	0.31	1,778	3	0.64	1,347	3	0.48	92,748	141
1990	7	15,378	60	0.95	7	0	0.90	9,987	16	0.68	155,051	134	0.31	3,392	5	0.61	4,944	9	0.47	188,759	224
1991	6	21,278	102	1.02	265	1	0.79	6,606	12	0.74	208,574	193	0.32	4,089	9	0.72	4,025	8	0.50	244,837	325
1992	7	23,468	104	0.99	485	1	0.88	4,807	8	0.68	106,832	108	0.33	5,513	13	0.74	3,306	6	0.45	144,411	240
1993	7	33,893	127	0.94	76	0	0.83	5,960	11	0.72	240,817	247	0.34	7,689	14	0.66	3,715	8	0.50	292,150	407
1994	8	23,713	66	0.85	1,844	7	0.98	10,231	17	0.69	257,749	256	0.33	9,621	18	0.66	7,271	13	0.48	310,429	377
1995	7	16,758	84	1.04	5,596	16	0.87	24,932	39	0.68	212,768	197	0.32	13,740	22	0.62	1,410	2	0.46	275,204	360
1996	5	42,112	223	1.06	191	0	0.49	11,614	19	0.69	350,806	378	0.34	16,072	44	0.78	2,909	5	0.47	423,704	670
1997	6	14,367	69	1.02	5,520	11	0.75	24,567	41	0.69	81,591	66	0.30	11,720	17	0.58	915	1	0.43	138,679	205
1998	4	15,672	62	0.96	1,088	5	1.05	2,070	3	0.67	169,971	144	0.31	10,881	14	0.56	5,441	8	0.42	205,123	236
1999	4	18,737	78	0.97	5,945	24	0.97	6,688	12	0.71	133,175	130	0.33	9,449	20	0.68	2,495	5	0.46	176,489	269
2000	5	57,643	180	0.88	8,121	44	1.09	10,743	16	0.66	114,297	126	0.35	5,042	9	0.64	1,408	2	0.46	116,722	188
2001	5	30,122	66	0.77	2,548	6	0.79	8,121	10	0.61	40,764	33	0.30	1,253	1	0.49	2,638	4	0.43	85,446	120
2002	4	8,174	21	0.82	1,009	3	0.92	6,380	7	0.56	38,256	36	0.32	2,935	3	0.51	557	1	0.41	57,311	71
2003	4	39,743	73	0.73	3,782	7	0.74	3,185	4	0.62	102,110	85	0.30	1,393	2	0.60	1,194	2	0.48	151,407	173
2004	5	23,206	37	0.69	510	1	0.86	6,374	8	0.62	58,598	52	0.31	11,472	16	0.58	2,771	5	0.48	102,931	119
2005	5	21,369	59	0.84	1,592	4	0.83	8,238	10	0.60	82,409	65	0.30	4,979	7	0.57	2,027	3	0.43	120,614	148
Avg.	5	24,903	87	0.91	2,040	7	0.87	8,499	13	0.66	140,434	134	0.32	6,589	12	0.63	2,746	5	0.47	180,971	248

Station		*Epischura*			*Diaptomus*			*Cyclops*			*Bosmina*			*Daphnia*			*Holopedium*			TOTALS	
2	No.	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass
Year	Samples	no/m^2	mg/m^2	mm	no/m^2	mg/m^2	mm	no/m^2	mg/m^2	mm	no/m^2	mg/m^2	mm	no/m^2	mg/m^2	mm	no/m^2	mg/m^2	mm	no/m^2	mg/m^2
1988	4	10,656	45	0.98	40	0	1.44	809	1	0.70	108,838	110	0.33	1,405	3	0.65	942	3	0.55	122,690	162
1989	5	10,306	35	0.90	0	0		1,261	2	0.66	48,235	40	0.30	420	1	0.63	553	1	0.46	60,775	79
1990	7	12,610	48	0.94	0	0		3,460	5	0.66	128,277	108	0.31	2,350	4	0.64	4,026	7	0.47	150,723	172
1991	6	19,285	80	0.97	1,274	4	0.89	4,277	8	0.74	154,341	132	0.31	3,347	6	0.65	5,083	10	0.49	187,607	240
1992	7	8,948	34	0.94	144	1	1.00	1,436	2	0.67	82,879	84	0.33	2,521	5	0.70	1,579	3	0.45	97,507	129
1993	7	19,033	70	0.93	773	1	0.69	3,882	5	0.62	175,106	157	0.32	2,570	5	0.67	3,988	7	0.47	205,352	245
1994	8	11,006	40	0.93	783	3	0.91	2,736	4	0.65	125,352	116	0.32	4,321	7	0.64	2,468	4	0.46	146,666	174
1995	7	12,193	44	0.92	1,168	4	0.94	9,054	11	0.61	111,525	98	0.31	8,902	12	0.58	1,152	1	0.4	143,994	170
1996	5	20,892	99	1.02	255	2	1.17	2,930	6	0.77	219,747	239	0.35	4,331	11	0.76	1,571	2	0.46	249,726	359
1997	6	13,677	57	0.97	3,468	7	0.75	3,822	5	0.64	86,060	63	0.29	9,652	13	0.56	924	1	0.41	117,601	146
2004	5	27,192	44	0.70	32	0	0.95	5,125	8	0.66	34,843	27	0.29	2,187	4	0.62	1,624	3	0.44	71,003	84
2005	5	22,282	60	0.83	0	0		2,850	4	0.63	49,992	37	0.29	815	2	0.73	900	1	0.38	76,839	104
Avg.	6	15,673	55	0.92	661	2	0.97	3,470	5	0.67	110,433	101	0.31	3,568	6	0.65	2,068	4	0.45	135,874	172

Appendix H. Adult sockeye salmon spawning estimates within the Afognak Lake system and useable spawning habitat estimates at Eggtake and Hatchery Creeks.

	Eggtake Creek				Hatchery Creek				Lake	
Year[a]	Live	Dead	Other[b]	Sub Total	Live	Dead	Other[b]	Sub Total	Shoal[b]	Total
1961	3,400	200		3,600	5,000	1,580		6,580	41,743	51,923
1978			11,224	11,224			5,666	5,666	35,811	52,701
1982[c]			16,362	16,362			31,840	31,840	70,853	119,055
Spawner Estimate Average:				10,395				14,695	49,469	74,560
1990[d]				6,595				9,712	n/a	n/a
2005[e]				3,448				9,916	n/a	n/a
Available Spawning Habitat Average:				5,022				9,814	n/a	n/a

[a] Data summarized from Sheridan 1961; Roelofs 1964; Schwarz pers. comm.; Willette 1984; White et. al 1990.
[b] Data were not separated into live or dead.
[c] Data estimates were obtained from a tagging study from Willette 1984.
[d] Available spawning habitat measurements were first reported in White et. al 1990, the actual survey was conducted at an undocumented prior date.
[e] Available spawning habitat measurements were collected with methods described in this document.